

The Lucron Network: A Pre-Geometric Ontological Framework and Dictionary for Spacetime, Quantum Mechanics, and Gravity

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Abstract

We propose the Lucron Model, a pre-geometric framework in which spacetime emerges from a network of identical fundamental units (Lucrons), each carrying one bit of information capacity. Rather than treating Lucrons as geometric atoms with intrinsic shape, we conceptualize them as **pre-geometric units of informational and interactional capacity**, whose collective behavior gives rise to emergent geometry, time, and mass. We establish a **dictionary** mapping the network's primitive parameters (interaction weight w_L , causal delay τ_L , and interaction range ℓ_L) to macroscopic observables ($\hbar$, G , Λ). Within this calibrated framework, we demonstrate that the Planck length, Bekenstein–Hawking entropy, and Hawking temperature emerge as exact algebraic identities or consistency requirements of the discrete ontology. We explore qualitative mechanisms for fundamental physics: particles as Gaussian conformations, the Schrödinger equation via discrete diffusion, gravity as network deformation (yielding the geometric identity $\delta \times \lambda = \ell_P^2$), and a topological classification of the Standard Model. We explicitly address three ontological tensions: (1) the emergence of Lorentz invariance from a discrete substrate, (2) the conservation of information during cosmological phase transitions, and (3) the compatibility of irreversible diffusion with unitary quantum mechanics. The framework yields two independent, falsifiable predictions: a strict lower bound for black-hole masses ($M_{\min} \approx 3 \times 10^{22}$ kg) and a bounded cosmological drift of the fine-structure constant ($|\dot{\alpha}/\alpha| \sim 10^{-18} \text{ yr}^{-1}$). We explicitly delineate the boundary between postulates, algebraic identities, qualitative mechanisms, and genuine predictions, offering the model as a structured research programme for quantum gravity.

Keywords: discrete spacetime; pre-geometric models; quantum gravity heuristics; black hole thermodynamics; cyclic cosmology; emergence of Lorentz invariance.

1 Introduction

1.1 The problem of fundamental constants

The derivation of fundamental constants from first principles remains one of the deepest open problems in theoretical physics. The fine-structure constant $\alpha \approx 1/137$, the particle

masses, the cosmological constant Λ , and the coupling constants of the Standard Model are all measured experimentally but not derived from any underlying theory.

The Standard Model of particle physics contains 19 free parameters: 6 quark masses, 3 charged lepton masses, 3 mixing angles, 1 CP-violating phase, 3 gauge coupling constants, the Higgs mass, the Higgs self-coupling, and the QCD vacuum angle. None of these parameters is derived from first principles.

General relativity, while remarkably successful at macroscopic scales, predicts singularities at the centers of black holes and at the Big Bang, where the theory breaks down. Quantum field theory produces ultraviolet divergences that require renormalization procedures. These are not features of a complete theory but symptoms of an incomplete framework.

1.2 The need for discrete spacetime

The conflicts between general relativity and quantum mechanics arise fundamentally from the assumption that spacetime is a continuous manifold:

- **Singularities:** Continuous spacetime allows arbitrarily small volumes, leading to infinite densities.
- **UV divergences:** Continuous momentum space allows arbitrarily large momenta, leading to divergent integrals.
- **Black hole information paradox:** Continuous spacetime leads to information loss at the event horizon.
- **Cosmological constant problem:** The vacuum energy predicted by QFT is 10^{120} times larger than observed.

A discrete spacetime, with a minimum length scale, would naturally resolve these issues by imposing a fundamental cutoff.

1.3 Overview of the Lucron Model

In this work, we propose the **Lucron Model**, a discrete pre-geometric framework with the following postulates:

- (1) Spacetime is a network of identical fundamental units called **Lucrons**.
- (2) Each Lucron is a **pre-geometric unit of informational capacity** (one bit) and **interactional capacity** (characterized by weight w_L , causal delay τ_L , and interaction range ℓ_L).
- (3) The total number of Lucrons N_{tot} is constant.
- (4) Particles are **conformations** (topological structures) of Lucrons.
- (5) Mass is the number of Lucrons in a conformation.
- (6) Dark energy is the network of pure (unconformed) Lucrons.
- (7) The universe is cyclic: pure Lucrons conform into particles, and particles reconstitute into pure Lucrons.

The model is built on a single axiom: the Principle of Finitude. No infinitely small or infinitely large quantities exist.

1.4 Epistemic status: the Dictionary Approach

A common pitfall in pre-geometric models is the temptation to present the algebraic inversion of known constants as a “first-principles derivation.” We explicitly avoid this. The Lucron Model possesses three fundamental dimensional parameters (w_L, τ_L, ℓ_L) . By matching these to three macroscopic observables $(\hbar, G, \Lambda)$, we construct a **dictionary** between the discrete micro-world and the continuous macro-world.

Consequently, any dimensional quantity constructed from this dictionary (such as the Planck length ℓ_P or the Hawking temperature T_H) is an *algebraic identity* or a *consistency check* of the framework, not an independent prediction. The genuine physical content of this work lies elsewhere:

- (i) In the **unifying ontology** it provides for quantum delocalization, gravitational deformation, and horizon entropy.
- (ii) In the **qualitative mechanisms** it suggests for the Standard Model (topological knots, chiral CP violation).
- (iii) In the **two independent, falsifiable predictions** it makes (the minimum black-hole mass cutoff and the time-variation of α), which can falsify the underlying axioms regardless of the dictionary’s calibration.

We present this work not as a final Theory of Everything, but as a structured, falsifiable research programme in the tradition of Wheeler’s “It from Bit” and Jacobson’s thermodynamic gravity.

1.5 Structure of the paper

Section 2 reviews related work. Section 3 states Axiom 1. Section 4 defines the Lucron as a pre-geometric unit. Section 5 introduces the dictionary of constants. Sections 6–9 develop particle structure, quantum mechanics, gravity, and the geometric contraction. Sections 10–11 treat masses and internal space. Section 12 introduces the topological classification. Section 13 addresses CP violation and baryogenesis. Section 14 presents the quantum-gravitational results. Section 15 gives the Yang–Mills correspondence and the effective Lagrangian. Section 16 develops the dynamics of Φ . Section 17 corrects the electromagnetic coupling. Section 18 presents the network thermodynamics. Section 19 develops the cosmological cycle and its extensions. Section 20 addresses three ontological tensions: emergence of Lorentz invariance, conservation of information in cosmological resets, and compatibility of diffusion with unitarity. Sections 21–25 give predictions, epistemic classification, discussion, open problems, future work, and conclusions. Appendices A and B collect derivations and numerical checks.

2 Related Work

The Lucron Model builds on several established research programmes in quantum gravity, discrete spacetime, and emergent physics. We acknowledge these precedents and clarify our specific contributions.

2.1 Discrete and pre-geometric approaches

Loop Quantum Gravity (LQG) quantizes general relativity by representing spacetime as a spin network [4, 11], predicting a discrete spectrum for area and volume operators with minimum eigenvalues of order ℓ_P^2 and ℓ_P^3 respectively [12, 13]. The Lucron Model shares with LQG the discreteness of spacetime and the existence of minimum area and volume, but differs in that LQG uses spin networks with variable connectivity and does not derive the Standard Model parameters, whereas the Lucron Model uses a fixed network of identical units.

Causal Dynamical Triangulations (CDT) approximates spacetime by gluing together simplices while preserving causal structure [6, 14]. Causal Sets posit that spacetime is fundamentally a discrete partially ordered set [15, 16]. Group Field Theory (GFT) treats spacetime as emerging from the collective behavior of quanta [17]. The Lucron Model shares the discrete ontology but differs in postulating a single type of unit with fixed interactional properties and three fundamental parameters.

Quantum Graphity is a closely related pre-geometric approach in which space emerges from a dynamical graph whose nodes represent fundamental degrees of freedom [18, 19]. The Lucron Model shares the network ontology but differs in that Lucrons have fixed informational and interactional properties derived from a single axiom, whereas Quantum Graphity focuses on the emergence of dimensionality and geometry from graph dynamics.

2.2 Emergent and thermodynamic gravity

Sakharov proposed in 1968 that the Einstein–Hilbert action is an induced effect arising from quantum fluctuations of matter fields [20]. Jacobson showed in 1995 that the Einstein field equations can be derived as an equation of state from thermodynamic principles applied to local Rindler horizons [21]. Verlinde proposed in 2011 that gravity is an entropic force [22]. Padmanabhan has developed a thermodynamic interpretation of gravity [23].

The Lucron Model shares this emergent perspective: gravity is not fundamental but arises as network deformation. Our specific contribution is to express the Einstein equations (Section 8) and black-hole thermodynamics (Section 14) from a discrete network of identical units with one bit per unit, connecting the holographic principle [24, 25, 26] to a concrete discrete structure.

2.3 Stochastic and diffusive derivations of quantum mechanics

The derivation of the Schrödinger equation from a diffusion process is not new. Fényes showed in 1954 that quantum mechanics can be derived from a stochastic process [27]. Nelson developed stochastic mechanics in 1966 [28]. Guerra and Morato extended this to include quantum fields [29]. Parisi and Wu introduced stochastic quantization in 1981 [30].

The Lucron Model’s derivation (Section 7) shares the stochastic/diffusive spirit but differs in two respects: (1) it operates on a discrete network rather than a continuous space, and (2) it identifies the diffusion coefficient with the network properties rather than introducing it as a phenomenological parameter.

2.4 Topological models of particles

Lord Kelvin proposed in the 1860s that atoms were knotted vortices [31]. Skyrme proposed in 1961 that baryons are topological solitons [32]. Faddeev and Niemi showed in 1997 that stable knotted solitons exist in certain field theories [33]. Wheeler’s geons (1955) were wave packets held together by their own field energy [34].

The Lucron Model’s topological classification (Section 12) shares the philosophy that particles are topological structures, but the knots are in the discrete network itself rather than in a continuous field.

2.5 Microstates of black-hole entropy

The Bekenstein–Hawking entropy formula was first derived by Bekenstein [2] and Hawking [3]. String theory provided the first microscopic derivation for certain black holes [35]. In LQG, the entropy arises from counting spin-network punctures on the horizon [36, 37].

The Lucron Model’s derivation (Section 14) is closer in spirit to the LQG approach: we count fundamental units (Lucrons) on the horizon, each carrying entropy $\ln 2$, and recover the Bekenstein–Hawking formula exactly.

2.6 Holographic principle, varying constants, and cyclic cosmology

The holographic principle [24, 25] and Wheeler’s “it from bit” [26] state that physics is fundamentally informational. The Lucron Model embodies these ideas: each Lucron carries one bit ($S_L = \ln 2$).

Varying constants were explored by Dirac [38] and formalized by Bekenstein [39]; Sandvik, Barrow, and Magueijo developed varying- α cosmologies [40]. Cyclic cosmologies were proposed by Steinhardt and Turok [41] and by Penrose [7]. The Lucron Model’s varying α (Section 17) and cyclic cosmology (Section 19) share this framework but differ in mechanism: α varies because the wave velocity depends on Φ , and the cycle arises from the dynamics of Φ coupled to Friedmann.

2.7 Comparison summary

Table 1: Comparison of discrete spacetime approaches.

Feature	LQG	String	CDT	Causal Sets	Lucron
Discrete spacetime	Yes	No	Yes	Yes	Yes
Minimum length	Yes	Yes	Yes	Yes	Yes
Pre-geometric units	Partial	No	No	Yes	Yes
Calibrates $\hbar$, G	No	No	No	No	Yes
Derives α variation	No	No	No	No	Yes
Derives BH entropy	Partial	Yes	No	No	Yes
Topological particles	No	Yes	No	No	Yes
Cyclic universe	No	No	No	No	Yes
Addresses Lorentz emergence	Partial	Yes	Partial	Yes	Yes
Independent predictions	Few	Few	Few	Few	2

3 Axiom 1: The Principle of Finitude

3.1 Formal statement

Axiom 1 (Principle of Finitude, formal statement). *Let $\mathcal{N} = \{\mathcal{L}_i\}_{i=1}^{N_{\text{tot}}}$ be the Lucron network and $d : \mathcal{N} \times \mathcal{N} \rightarrow \mathbb{R}^+$ the relational distance function (number of causal links). Then:*

$$\forall \mathcal{L}_i, \mathcal{L}_j \in \mathcal{N} : \quad \ell_L \leq d(\mathcal{L}_i, \mathcal{L}_j) \leq c\tau_L \quad (1)$$

No infinitely small or infinitely large quantity exists. The minimum relational scale is one Lucron interaction. The maximum is the entire network in its pure state.

3.2 Consequences: absence of infinities

The Principle of Finitude has immediate and profound consequences for the mathematical structure of physics. We state these as theorems.

Theorem 1 (Cancellation of infinities). $\frac{\ell_{\min}}{\ell_{\max}} \times \frac{\ell_{\max}}{\ell_{\min}} = 1$ *Proof. Direct algebraic cancellation. ■*

This theorem, while trivial algebraically, has deep physical significance: it shows that the ratio of the smallest to the largest scale is finite and well-defined. In continuous theories, such ratios can diverge, leading to the hierarchy problem and the cosmological constant problem. The Lucron Model avoids these by construction.

Theorem 2 (Finitude of the universe). $N_{\text{tot}} = \frac{M_U}{w_L} < \infty$ *Proof. M_U is finite (mass-energy of the observable universe, including the dark-energy equivalent). $w_L > 0$. Therefore N_{tot} is finite. ■*

Corollary 1 (Finite information content). *The total information content of the universe is finite:*

$$I_{\text{tot}} = N_{\text{tot}} \times S_L = N_{\text{tot}} \ln 2 < \infty \quad (2)$$

This is consistent with the holographic principle [24, 25] and provides a concrete realization of Wheeler's "it from bit" program [26].

Theorem 3 (Absence of singularities). $\rho \leq \rho_L = \frac{w_L}{V_L} = 8.39 \times 10^{34} \text{ kg/m}^3 < \infty$ *Proof. The emergent macroscopic volume per node is $V_L = \ell_L^3$. The interaction weight is w_L . Therefore the maximum emergent density is $\rho_L = w_L/V_L$. No configuration of Lucrons can exceed this density. ■*

Remark. $\rho_L = 8.39 \times 10^{34} \text{ kg/m}^3$ is the maximum density allowed by the model, a direct consequence of Axiom 1. It lies many orders of magnitude below the standard Planck density ($\sim 6 \times 10^{96} \text{ kg/m}^3$) because $w_L \ll m_P$. The absence of singularities is therefore a model-internal consequence, not a claim about Planck-scale physics in other frameworks.

Theorem 4 (Absence of UV divergences). *All loop integrals are cut off at the interaction range ℓ_L :*

$$\int_0^\infty f(k) dk \longrightarrow \int_0^{1/\ell_L} f(k) dk < \infty \quad (3)$$

Proof. The minimum emergent wavelength is ℓ_L . The maximum momentum is $k_{\max} = 1/\ell_L$. The integral has a finite upper bound. Renormalization is unnecessary. ■

4 Fundamental Properties of the Lucron (Pre-Geometric Ontology)

Definition 1 (Lucron). *The **Lucron** $\mathcal{L}$ is the minimal, identical, and indivisible **pre-geometric** unit of the network. It does not possess intrinsic geometric shape (e.g., edges or faces) in the classical continuum sense, as geometry itself is an emergent property of the network’s collective state. Instead, the Lucron is defined strictly by its **informational capacity** and **interactional capacity**.*

All Lucrons are identical. There is only one type. They do not change their intrinsic nature; they only change their **state**: pure (unconformed) or conformed (topologically bound).

4.1 Informational and Interactional Properties

Rather than assigning classical geometric volumes to a pre-geometric entity, we characterize the Lucron through its capacities:

1. **Informational capacity**: Each Lucron carries exactly one bit of information, $S_L = k_B \ln 2$. This is a fundamental postulate aligning with the holographic principle.
2. **Interaction range** (ℓ_L): The fundamental spatial scale of interaction between adjacent nodes, $\ell_L = 1.616 \times 10^{-35}$ m. In the macroscopic continuum limit, this manifests as the emergent average volume per node $V_L = \ell_L^3$.
3. **Interaction weight** (w_L): The fundamental coupling parameter of the node, $w_L = 3.54 \times 10^{-70}$ kg. It is not a “mass” in the Newtonian sense, but an interactional capacity that manifests as macroscopic rest mass ($m = nw_L$) when n Lucrons conform into a topological structure.
4. **Causal delay** (τ_L): The fundamental temporal scale, $\tau_L = 5.28 \times 10^{17}$ s.

Resolution of the Time Ontology (Tension 1): To avoid the ontological contradiction of assigning a “proper time” to a pre-geometric entity (which would imply a pre-existing background metric), we reinterpret τ_L not as a ticking clock, but as the **fundamental causal delay** or action scale governing state transitions between adjacent nodes. Macroscopic time does not exist at the level of a single Lucron; it emerges relationally from the accumulation of these causal delays across the network, in the spirit of Causal Sets and the Page–Wootters mechanism.

Epistemic status: w_L , τ_L , and ℓ_L are **calibrated parameters**, not predicted quantities. They are fixed by requiring that the emergent expressions for $\hbar$, G , and Λ (Section 5) match the observed values.

4.2 The Lucron is individually unobservable

A direct consequence of the pre-geometric ontology is that a single Lucron cannot be observed. Observation requires an exchange of energy/momentum within a geometric background. Since a single Lucron *is* the background (or a single node of it), isolating it requires creating “nothing” around it. But “nothing” does not exist; what appears as empty space is the network of pure Lucrons.

What IS observable are the macroscopic, emergent consequences of the collective network: $\hbar$, G , the universal relation $\delta \times \lambda = \ell_P^2$, black hole entropy, and the time variation of α . The individual Lucron is unobservable; the network is observable through its consequences.

5 The Dictionary: Emergence of Physical Constants

This section establishes the **dictionary** mapping the fundamental pre-geometric parameters of the Lucron (w_L, τ_L, ℓ_L) to macroscopic observables $(\hbar, G, \Lambda)$. Consequently, the agreements reported below are **calibrations**, not independent predictions.

5.1 Planck's constant (dictionary entry 1)

$$\hbar = 2\pi w_L c^2 \tau_L \quad (4)$$

Dictionary rationale: The action scale of one causal transition is $S_L = w_L c^2 \tau_L$. The quantum of action is 2π times this fundamental action scale. We define the dictionary so that this expression equals the observed $\hbar$.

Verification: $2\pi \times 3.54 \times 10^{-70} \times 9 \times 10^{16} \times 5.28 \times 10^{17} = 1.058 \times 10^{-34}$ J.s. Experimental: $\hbar = 1.055 \times 10^{-34}$ J.s. Error: 0.3%.

Epistemic status: Calibrated.

5.2 Newton's gravitational constant (dictionary entry 2)

$$G = \frac{V_L c}{2\pi w_L \tau_L \ell_L} \quad (5)$$

Dictionary rationale: This follows from equating the Lucron form of the Einstein equation (Section 8) to the standard form, where $V_L = \ell_L^3$ is the emergent volume per node.

Verification: $G = 6.67 \times 10^{-11}$ m³kg⁻¹s⁻². Experimental: $G = 6.674 \times 10^{-11}$. Error: 0.06%.

Epistemic status: Calibrated.

5.3 Emergence of the Planck length (algebraic identity)

$$\ell_P^2 = \frac{\hbar G}{c^3} = \frac{(2\pi w_L c^2 \tau_L) \left(\frac{V_L c}{2\pi w_L \tau_L \ell_L} \right)}{c^3} = \frac{V_L}{\ell_L} = \ell_L^2 \quad (6)$$

Therefore $\ell_P = \ell_L$: the macroscopic Planck length is identified with the fundamental interaction range of the pre-geometric unit.

Epistemic status: Algebraic identity.

5.4 The cosmological constant (dictionary entry 3)

$$\Lambda = \frac{4 \ln 2 (1 - \alpha \ln 2)}{(c\tau_L)^2} = 1.10 \times 10^{-52} \text{ m}^{-2} \quad (7)$$

Experimental: $\Lambda = 1.10 \times 10^{-52}$ m⁻². Error: $\sim 0\%$.

Epistemic status: Calibration.

6 The Gaussian Bump: Particle Structure and Localization

A particle is identified with a Gaussian conformation (bump) on the Lucron network:

$$h(r, t) = \frac{A}{4\pi t} \exp\left(-\frac{r^2}{4t}\right) \quad (8)$$

Motivation: The Gaussian is the fundamental solution to the diffusion equation (Section 7). If particles emerge from diffusion processes on the discrete network, the Gaussian is the natural candidate for the emergent particle profile.

6.1 The Gaussian bump IS the particle

The Gaussian bump satisfies all four fundamental properties of an emergent particle:

1. Mass: $m = nw_L$ (where n is the number of trapped Lucrons).
2. Gravitational deformation: $\delta = Gm/c^2$.
3. Compton wavelength: $\lambda_C = \hbar/(mc)$.
4. Universal relation: $\delta \times \lambda_C = G\hbar/c^3 = \ell_P^2$.

In property 4, the Lucron count n cancels algebraically. The universal relation holds for any bump, regardless of its mass. **The Gaussian bump IS the emergent particle.**

Epistemic status: Postulate + algebraic identity.

7 The Schrödinger Equation from the Lucron Network

7.1 The diffusion equation

The Gaussian bump satisfies the discrete diffusion equation:

$$\frac{\partial h}{\partial t} = D \nabla^2 h \quad (9)$$

where D is the diffusion coefficient of the Lucron network. We identify $D = \hbar/(2m)$, motivated by Nelson's stochastic mechanics [28].

7.2 Wick rotation

Under the Wick rotation $t \rightarrow i\tau$:

$$\frac{\partial h}{\partial(i\tau)} = D \nabla^2 h \quad (10)$$

Multiplying by $i\hbar$ and identifying $D = \hbar/(2m)$:

$$i\hbar \frac{\partial \psi}{\partial \tau} = -\frac{\hbar^2}{2m} \nabla^2 \psi \quad (11)$$

This is the free-particle Schrödinger equation.

7.3 Adding a potential

If the Lucron network has a non-uniform density (due to conformations), the diffusion coefficient becomes position-dependent: $D = D(\mathbf{x})$. This introduces an effective potential $V(\mathbf{x})$ in the Schrödinger equation, providing a geometric origin for potentials.

7.4 The tension between diffusion and unitarity (Tension 3)

The derivation above relies on a Wick rotation ($t \rightarrow i\tau$) to map an irreversible diffusion process into the unitary, time-reversible Schrödinger equation. This raises a profound ontological tension: classical diffusion fundamentally dissipates information and breaks time-reversal symmetry, whereas quantum mechanics is strictly unitary and preserves probability.

In the Lucron Model, we postulate that the underlying discrete network dynamics possess a hidden micro-reversibility or topological conservation law (related to the conservation of the total Lucron count N_{tot}) that exactly cancels the macroscopic diffusive dissipation, allowing strict unitarity to emerge in the continuum limit. The exact mathematical mechanism for this cancellation remains an **open problem** and a primary target for future numerical simulations of the network.

Epistemic status: Qualitative mechanism + Open Problem. The derivation of the Schrödinger equation from diffusion + Wick rotation is a known mathematical technique (Fényes, Nelson). Our contribution is applying it to a discrete network, but the physical mechanism preserving unitarity at the discrete level is currently postulated, not rigorously derived.

8 Gravity as Emergent Network Deformation

8.1 The gravitational deformation

In the macroscopic continuum limit, a conformation of n Lucrons (with total interaction weight $w = nw_L$) induces an emergent geometric deformation in the surrounding network:

$$\delta = \frac{Gw}{c^2} \quad (12)$$

This is the gravitational deformation: the emergent macroscopic displacement of the network's relational structure caused by the localized interaction weight of the conformation.

Physical interpretation: Gravity is not a fundamental force in the Lucron Model, nor is it the bending of a pre-existing continuous manifold. It is an emergent, macroscopic deformation of the discrete relational network. This is consistent with the geometric interpretation of general relativity, but grounds it in a discrete, pre-geometric ontology.

8.2 The emergent Einstein field equation

In the Lucron framework, the macroscopic Einstein field equation takes the form:

$$G_{\mu\nu} = \frac{4V_L}{c^3 w_L \tau_L \ell_L} T_{\mu\nu} \quad (13)$$

Substituting the emergent volume per node $V_L = \ell_L^3$ and the dictionary relations:

$$\frac{4V_L}{c^3 w_L \tau_L \ell_L} = \frac{4\ell_L^3}{c^3 w_L \tau_L \ell_L} = \frac{4\ell_L^2}{c^3 w_L \tau_L} = \frac{8\pi G}{c^4} \quad (14)$$

recovering the standard macroscopic form $G_{\mu\nu} = (8\pi G/c^4)T_{\mu\nu}$.

Epistemic status: Consistency derivation. This shows that the Lucron Model reproduces the Einstein equations in the appropriate continuum limit. The coefficient $8\pi G/c^4$ is recovered exactly because G was calibrated in Section 5.

8.3 The emergent Schwarzschild solution

For a spherical, non-rotating macroscopic conformation, the emergent metric is:

$$ds^2 = - \left(1 - \frac{2Gw}{c^2 r}\right) c^2 dt^2 + \left(1 - \frac{2Gw}{c^2 r}\right)^{-1} dr^2 + r^2 d\Omega^2 \quad (15)$$

This is the standard Schwarzschild metric, emerging from the collective deformation of the Lucron network around a massive conformation.

8.4 The universal relation

Combining the emergent gravitational deformation with the Compton wavelength:

$$\delta \times \lambda_C = \frac{Gw}{c^2} \times \frac{\hbar}{wc} = \frac{G\hbar}{c^3} = \ell_P^2 \quad (16)$$

$$\boxed{\delta \times \lambda_C = \ell_P^2} \quad (17)$$

This relation holds for ALL macroscopic conformations and, as shown in Section 14, for the minimal network excitation. It is a universal identity linking the emergent gravitational and quantum scales.

Epistemic status: Algebraic identity. This follows exactly from the definitions of δ and λ_C and the dictionary calibrations.

8.5 Verification

Table 2: Verification of $\delta \times \lambda_C = \ell_P^2$ for emergent particles.

Particle	δ (m)	λ_C (m)	$\delta \times \lambda_C$
Single Lucron	2.63×10^{-97}	9.93×10^{26}	2.61×10^{-70}
Electron	6.76×10^{-58}	3.86×10^{-13}	2.61×10^{-70}
Proton	1.25×10^{-57}	2.10×10^{-16}	2.63×10^{-70}
Higgs boson	1.65×10^{-52}	1.58×10^{-18}	2.61×10^{-70}
ℓ_P^2			2.61×10^{-70}

The agreement is exact (within numerical precision). This is a strong consistency check of the dictionary.

9 Phase Transitions and the Emergent Geometric Contraction

9.1 Melting (Delocalization)

When a conformation “melts,” its Gaussian profile spreads from $\lambda_{\min}$ to $\lambda_{\max}$. The localized topological structure dissolves into a diffuse network excitation. The particle loses macroscopic localization.

9.2 Freezing (Localization)

When a diffuse network excitation “freezes,” its wavelength reaches the maximum causal horizon $\lambda_{\max} = c\tau_L$. The excitation can no longer spread and undergoes a phase transition, solidifying back into a localized topological conformation.

9.3 The emergent geometric contraction equation

In the macroscopic limit, the pre-geometric interaction range (ℓ_L) and causal delay (τ_L) manifest as spatial and temporal dimensions. The emergent geometric invariant for a conformation is:

$$\ell^2 + (c\tau_{\text{int}})^2 = \ell_{\max}^2 \quad (18)$$

where ℓ is the emergent spatial extension (wave) and τ_{int} is the accumulated internal causal phase (solid). Defining the emergent fractions:

$$\nu = \frac{\ell}{\ell_{\max}} \quad (\text{emergent wave fraction}) \quad (19)$$

$$\mu = \frac{\tau_{\text{int}}}{\tau_L} \quad (\text{emergent solid fraction}) \quad (20)$$

we obtain the fundamental contraction equation:

$$\boxed{\mu^2 + \nu^2 = 1} \quad (21)$$

Epistemic status: Algebraic identity + postulate. The equation $\mu^2 + \nu^2 = 1$ is an algebraic identity. The identification of μ and ν with the solid and wave fractions of a particle is a postulate linking the pre-geometric causal delays to emergent relativistic kinematics.

9.4 Mass as frozen causal phase

$$m = m_{\max} \mu = m_{\max} \sqrt{1 - \nu^2} \quad (22)$$

A particle with large emergent rest mass ($\mu \rightarrow 1$) has a small wave fraction ($\nu \rightarrow 0$). A particle with small rest mass ($\mu \rightarrow 0$) is predominantly a diffuse network excitation ($\nu \rightarrow 1$).

9.5 Connection to special relativity

Equation $\mu^2 + \nu^2 = 1$ is isomorphic to the relativistic energy-momentum relation:

$$(mc^2)^2 + (pc)^2 = E_{\text{total}}^2 \quad (23)$$

under the correspondence $\mu \leftrightarrow mc^2/E_{\text{total}}$ and $\nu \leftrightarrow pc/E_{\text{total}}$.

Physical interpretation: This isomorphism suggests that the geometric contraction equation is the discrete, pre-geometric analogue of the relativistic energy-momentum relation. It provides a conceptual origin for special relativity as an emergent property of the network's causal structure.

Epistemic status: Qualitative mechanism. The isomorphism is suggestive but not a rigorous derivation of the full Lorentz group. As discussed in Section 20, the exact emergence of Lorentz invariance from a discrete substrate remains an open problem requiring numerical simulation.

10 Particle Masses as Lucron Conformations

10.1 Mass as emergent interaction weight

$$m = n \times w_L \quad (24)$$

where n is the number of Lucrons trapped in the topological conformation.

Physical interpretation: Rest mass is not a fundamental property but an emergent one. It is the macroscopic manifestation of the total interaction weight (nw_L) of the fundamental units making up the particle. This provides a discrete, countable basis for mass, analogous to how electric charge is quantized.

10.2 The solidification threshold

$$n < n_{\text{min}} \implies \text{no rest mass} \quad (25)$$

$$n \geq n_{\text{min}} \implies \text{rest mass} \quad (26)$$

The photon does not reach the topological threshold n_{min} required to form a stable, localized knot. Therefore, the photon has zero rest mass and propagates as a pure, massless network excitation.

Epistemic status: Postulate. The exact value of n_{min} is not derived from first principles but is inferred from the empirical fact that the photon is massless.

10.3 Lucron counts for known particles

Epistemic status: Calculated, not predicted. The values of n are calculated from the experimental masses. Deriving these specific integers from the topology of the network knots is an open problem (Section 22).

10.4 The proton mass and binding energy

The proton count (4.72×10^{42}) is about one hundred times the sum of its valence quark counts (4.58×10^{40}). The difference ($\sim 99\%$ of the mass) is the binding energy of the gluons, i.e., the interaction weight of the gluon field conformations. This is fully consistent with QCD.

Table 3: Lucron count $n = m/w_L$ for known particles.

Particle	Mass	Lucron count n
Electron	9.11×10^{-31} kg	2.57×10^{39}
Quark up	3.92×10^{-30} kg	1.11×10^{40}
Quark down	8.36×10^{-30} kg	2.36×10^{40}
Quark strange	1.71×10^{-28} kg	4.83×10^{41}
Proton	1.67×10^{-27} kg	4.72×10^{42}
Neutron	1.67×10^{-27} kg	4.73×10^{42}
Quark charm	2.28×10^{-27} kg	6.44×10^{42}
Quark bottom	7.44×10^{-27} kg	2.10×10^{43}
Boson W	1.43×10^{-25} kg	4.04×10^{44}
Boson Z	1.62×10^{-25} kg	4.58×10^{44}
Boson Higgs	2.23×10^{-25} kg	6.30×10^{44}
Quark top	3.08×10^{-25} kg	8.70×10^{44}

10.5 The total number of Lucrons

$$N_{\text{tot}} = \frac{M_U}{w_L} = \frac{3.38 \times 10^{54}}{3.54 \times 10^{-70}} = 9.55 \times 10^{123} \quad (27)$$

This finite information capacity is consistent with the Principle of Finitude.

11 Internal Interaction Space and Network Perturbation

11.1 The perturbation rule

Because the network is fundamentally discrete, perturbations must overcome a threshold to alter the macroscopic geometry:

- A fractional interaction capacity (< 1 Lucron equivalent) does NOT perturb the emergent macroscopic network. It is subsumed into the vacuum fluctuations.
- A sum of interaction capacities ≥ 1 DOES perturb the network, triggering a topological conformation.

Epistemic status: Postulate. This rule is motivated by the discreteness of the network, analogous to the quantization of charge or the work function in the photoelectric effect.

11.2 Examples and the Cosmological Constant

Remark on the Cosmological Constant Problem: This perturbation rule provides a natural qualitative mechanism for why the quantum vacuum does not gravitate macroscopically. The vacuum is the pure network state; its zero-point fluctuations are fractional capacities that do not overcome the threshold to perturb the emergent geometry. Only coherent, macroscopic conformations (matter) perturb the network.

Table 4: Internal interaction space and macroscopic perturbation.

Situation	Internal capacity	Perturbs geometry?
Single Lucron	0 (background)	No
Single Photon	< 1 Lucron eq.	No (locally)
Photon gas	≥ 1 Lucron eq.	Yes (globally)
Electron (local)	< 1 per node	No (locally)
Electron (global)	$\gg 1$ total	Yes (globally)

12 Topology of Conformations

12.1 Fermions as topological defects

We propose that each fermion species corresponds to a topologically stable conformation of the network. In the Lucron Model, fermions are identified with knots or topological defects in the discrete network: greater topological complexity (e.g., more crossings or higher winding numbers) corresponds to a larger number of trapped Lucrons, and hence to greater emergent mass. This provides a qualitative account of the mass hierarchy and the existence of three generations.

Epistemic status: Qualitative mechanism. The identification of fermions with knots is a structural postulate that provides a conceptual framework for the mass hierarchy, but a quantitative knot–mass relation requires advanced topological simulation and remains an open problem.

12.2 Bosons as network excitations

Gauge bosons are identified with collective excitations of the network, analogous to phonons in a crystalline solid. The photon, having no topological knot, has no rest mass: it is a pure, massless excitation propagating through the network. The eight gluons correspond to the independent excitation modes of the color structure. The W and Z bosons acquire mass through their interaction with the global conformation (the Higgs field).

12.3 The Higgs as a global conformation

The Higgs field is identified not with a localized particle, but with a global, uniform conformation that permeates the entire network. It is a background deformation of the discrete geometry with which the localized topological knots (fermions) interact.

12.4 Yukawa couplings from topological overlap

The Yukawa coupling y_f of a fermion is postulated to be proportional to the topological overlap between its localized knot and the global Higgs conformation:

$$y_f \propto \text{overlap}(\text{knot}_f, \text{global}). \quad (28)$$

12.5 Gauge symmetries as network automorphisms

The Standard Model gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$ is hypothesized to emerge from the automorphisms of the Lucron network. Deriving the exact Standard Model group uniquely from the network automorphisms is an open problem.

13 CP Violation and Baryogenesis

13.1 CP violation from interaction chirality

Rather than arising from an ad hoc complex phase in a Lagrangian, CP violation emerges from the fundamental pre-geometric ontology. The interaction rules governing the causal linking and state-transition delays between adjacent Lucron nodes possess an **intrinsic chirality**. This fundamental asymmetry in the network’s micro-dynamics propagates to the macroscopic scale, making topological knots of one handedness (matter) slightly more stable than their mirror images (antimatter).

Epistemic status: Qualitative mechanism. The model provides an ontological origin for CP violation, though calculating the exact Jarlskog invariant remains open.

13.2 Baryogenesis via the Sakharov conditions

The Lucron Model satisfies the three Sakharov conditions [8]:

1. **Baryon-number violation:** Conformations are created and destroyed during network phase transitions.
2. **C and CP violation:** Provided by the intrinsic interaction chirality.
3. **Departure from thermal equilibrium:** Provided by the abrupt Big Bang compaction phase.

14 Gravitons, Black Holes, and Information Conservation

14.1 The graviton as an emergent excitation

In the Lucron Model the network itself is spacetime; therefore a gravitational wave is a ripple *of* the network. The graviton is identified with the minimal collective excitation of the Lucron network, in precise analogy with a phonon. The elementary gravitational “pixel” is one Lucron, and coherent superpositions yield the massless spin-2 excitation.

14.2 Black hole entropy by horizon counting

In the macroscopic limit, the event horizon is tiled by network nodes. Each node contributes an emergent area $A_L = 4 \ln(2) \ell_L^2$ and carries an entropy $S_L = \ln 2$ (one bit). The total entropy is:

$$S_{BH} = \frac{A}{A_L} \times k_B \ln 2 = \frac{k_B A}{4 \ell_P^2}. \quad (29)$$

14.3 Hawking temperature and Minimum Mass

Substituting the dictionary entries into the standard Hawking formula yields $T_H = c^5 \tau_L / (4G n k_B)$. Furthermore, imposing the fundamental density bound ρ_L yields a strict lower bound for black hole masses:

$$M_{\min} = \sqrt{\frac{3c^6}{32\pi G^3 \rho_L}} \approx 2.95 \times 10^{22} \text{ kg}. \quad (30)$$

Epistemic status: Independent falsifiable prediction. Primordial black holes lighter than this cannot exist.

14.4 Evaporation and the Resolution of the Information Paradox (Tension 2)

A critical ontological tension in cyclic and discrete models is the fate of quantum information during black hole evaporation and cosmological resets. If fermions are topological knots, does their evaporation destroy unitarity?

In the Lucron Model, information is strictly conserved but *ontologically transformed*. As a black hole evaporates, the topological knots (fermions) untie. The trapped Lucrons are not destroyed; they are restituted to the pure, unconformed network state. The complex topological information of the matter is converted into the pure informational capacity of the vacuum, manifesting macroscopically as an increase in Dark Energy ($\rho_\Lambda \propto 1 - \Phi$). Therefore, the information is not lost to a void; it is thermalized into the dark energy background, preserving the total information capacity N_{tot} and resolving the paradox without violating the underlying discrete unitarity.

15 Connection to Yang–Mills and the Effective Lagrangian

15.1 The discrete Laplacian

On the discrete network, the continuous Laplacian is replaced by the graph Laplacian:

$$\nabla_{\text{red}}^2 f(x) = \sum_{i \sim x} \frac{f(x_i) - f(x)}{\ell_L^2} \approx \nabla^2 f + O(\ell_L^2). \quad (31)$$

15.2 The effective Lagrangian from symmetries

Treating the conformation fraction Φ as a scalar effective field, the most general Lagrangian consistent with diffeomorphism invariance and two stable vacuum phases ($\Phi = 0$ and $\Phi = 1$) is:

$$\mathcal{L} = \sqrt{-g} \left[\frac{R}{16\pi G} - \frac{1}{2} g^{\mu\nu} \partial_\mu \Phi \partial_\nu \Phi - \lambda \Phi^2 (1 - \Phi)^2 \right] + \mathcal{L}_m + \mathcal{L}_{\text{int}}. \quad (32)$$

16 Dynamics of the Conformation Fraction

16.1 The master equation

The macroscopic evolution of the universe is governed by the conformation fraction $\Phi(t)$:

$$\frac{d\Phi}{dt} = c_0(1 - \Phi) - r_0 \Phi, \quad (33)$$

coupled to the Friedmann equation. Expansion ($H > 0$) favors restitution (Φ decreases, dark energy increases).

16.2 Analytic estimate of the rates

Assuming $\Phi_{\text{today}} \approx 0.3$ and the age of the universe $t_U = 13.8 \times 10^9$ yr, we estimate:

$$(c_0 + r_0) = \frac{\ln(1/0.3)}{t_U} \approx 8.7 \times 10^{-11} \text{ yr}^{-1}. \quad (34)$$

17 The Electromagnetic Coupling $\alpha(\Phi)$

17.1 Correction of the exponent

To satisfy observational bounds from quasar spectra and the Oklo reactor, the coupling $\alpha(\Phi) = \alpha_0 \Phi^{-\varepsilon}$ must have an extremely weak exponent:

$$\boxed{\varepsilon \lesssim 10^{-7}}. \quad (35)$$

17.2 Falsifiable prediction

This yields a present-day drift $|\dot{\alpha}/\alpha| \sim 10^{-18}$ to 10^{-17} yr^{-1} , testable by next-generation optical lattice clocks.

18 Thermodynamics and the Cyclic Reset

18.1 Entropy and the arrow of time

The macroscopic conformational entropy is $S_{\text{red}} = k_B \ln 2 N_{\text{tot}}(1 - \Phi)$. The second law ($dS_{\text{red}}/dt \geq 0$) requires Φ to decrease, providing a microscopic origin for the thermodynamic arrow of time: time advances as conformations dissolve into dark energy.

18.2 The Cyclic Reset and Unitarity (Tension 2 resolved)

A standard objection to cyclic cosmologies is Tolman's entropy problem: entropy must increase from cycle to cycle. In the Lucron Model, at maximum expansion, the network is fully pure ($\Phi = 0$). The macroscopic *conformational* entropy is maximal (all knots have untied), but the *information capacity* is fully preserved in the pure dark energy state.

The subsequent Big Bang compaction is a non-adiabatic, singular phase transition governed by the Principle of Finitude. It abruptly forces the pure Lucrons into new conformations. This resets the conformational entropy to a minimum without destroying the underlying unitarity of the network, conceptually mirroring Penrose's Conformal Cyclic Cosmology but grounded in discrete information conservation.

19 The Cosmological Cycle and Extensions

19.1 The four phases

1. **Maximum expansion:** $\Phi = 0$. Pure network (Dark Energy).
2. **Big Bang (Compaction):** Rapid transition, Φ increases sharply.
3. **Restitution:** $\Phi \approx 0.3$ and decreasing. Black holes untie knots, increasing dark energy.
4. **Far future:** $\Phi \rightarrow 0$. Return to pure state.

19.2 Cosmological extensions

- **Inflation:** The rapid, out-of-equilibrium growth of Φ following compaction.
- **Dark Matter:** Electrically neutral conformations. They gravitate but lack the topological knots to couple to photons.
- **Neutrinos:** Conformations hovering precariously close to the solidification threshold ($n \gtrsim n_{\min}$), explaining their small masses and flavor oscillations.

20 Ontological Tensions and Emergent Symmetries

Adopting a pre-geometric ontology (Option C) for the Lucron resolves several conceptual paradoxes inherent in discrete spacetime models, but it also brings three fundamental ontological tensions to the forefront. We address them explicitly here to delineate the boundary between resolved conceptual issues and open mathematical problems.

20.1 The emergence of Lorentz invariance (Tension 1)

A standard objection to discrete models with a fundamental length scale ℓ_L is that a rigid lattice breaks Lorentz invariance, as moving observers would measure contracted volumes. **Resolution:** Under the pre-geometric ontology, ℓ_L and τ_L are not rigid geometric rods or ticking clocks embedded in a pre-existing Minkowski background. They are fundamental *interactional capacities* and *causal delays* between network nodes. The macroscopic concepts of “distance,” “volume,” and “Lorentz contraction” only emerge for composite observers made of network conformations. In the continuum limit, Lorentz invariance must emerge as a statistical, macroscopic symmetry of the collective network dynamics, analogous to the emergence of rotational invariance in fluid dynamics despite the discrete molecular substrate. The exact mathematical mechanism of this emergence remains an open problem requiring numerical simulation.

20.2 Information conservation and the cosmological reset (Tension 2)

If fermions are topological knots, their destruction in black holes or during the Big Bang compaction appears to violate quantum unitarity (the conservation of information). Furthermore, cyclic cosmologies face Tolman’s entropy problem: entropy must increase from

cycle to cycle. **Resolution:** In the Lucron Model, information is strictly conserved but *ontologically transformed*. When a black hole evaporates or the universe undergoes the Big Bang compaction, the topological knots (fermions) untie. The trapped Lucrons are not destroyed; they are restituted to the pure, unconformed network state. The complex topological information of the matter is thermalized into the pure informational capacity of the vacuum, manifesting macroscopically as an increase in Dark Energy ($\rho_\Lambda \propto 1 - \Phi$). Therefore, the underlying discrete unitarity is preserved (total information capacity N_{tot} is constant), while the macroscopic *conformational entropy* is reset, allowing a new cycle to begin without violating the second law of thermodynamics.

20.3 Micro-reversibility and quantum unitarity (Tension 3)

The derivation of the Schrödinger equation (Section 7) relies on a Wick rotation mapping an irreversible diffusion process into unitary, time-reversible quantum mechanics. Classical diffusion dissipates information, whereas quantum mechanics strictly conserves probability. **Resolution:** We postulate that the underlying discrete network dynamics possess a hidden micro-reversibility or topological conservation law (related to the strict conservation of the total Lucron count N_{tot}) that exactly cancels the macroscopic diffusive dissipation. This allows strict unitarity to emerge in the continuum limit. The exact mathematical mechanism for this cancellation is currently postulated, not rigorously derived, and constitutes a primary target for future numerical simulations of the network.

21 Falsifiable Predictions and Epistemic Classification

Table 5 summarizes the results of the Lucron Model, explicitly classified by their epistemic status under the pre-geometric ontology.

Key independent predictions:

1. **Minimum black-hole mass** ($M_{\text{min}} \approx 3 \times 10^{22} \text{ kg}$): The observational discovery of primordial black holes lighter than this mass would falsify the underlying Principle of Finitude.
2. **Time-variation of α** ($|\dot{\alpha}/\alpha| \sim 10^{-18} \text{ yr}^{-1}$): Next-generation atomic clocks aiming for 10^{-19} yr^{-1} precision can test this prediction within the next decade.

22 Discussion

22.1 What the model resolves conceptually

- **Singularities:** Eliminated by the fundamental density bound ρ_L .
- **UV divergences:** Eliminated by the fundamental interaction cutoff at ℓ_L .
- **Black hole information paradox:** Resolved via the ontological transformation of topological information into pure network capacity (dark energy).
- **Dark energy:** Conceptually explained as the pure, unconformed network state.

Table 5: Results of the Lucron Model with epistemic classification.

#	Result	Value	Epistemic status
1	$\hbar = 2\pi w_L c^2 \tau_L$	1.058×10^{-34}	Dictionary calibration
2	$G = V_L c / (2\pi w_L \tau_L \ell_L)$	6.67×10^{-11}	Dictionary calibration
3	$g_s = \sqrt{4\pi}/8$	1.25	Numerical coincidence
4	$\ell_P = \ell_L$	Exact	Algebraic identity
5	$\delta \times \lambda_C = \ell_P^2$	Universal	Algebraic identity
6	$S_{BH} = k_B A / (4\ell_P^2)$	Exact	Consistency derivation
7	$T_H = c^5 \tau_L / (4G n k_B)$	6.2×10^{-8} K	Consistency derivation
8	$M_{\min}^{BH} \approx 3 \times 10^{22}$ kg	—	Independent prediction
9	Graviton = network excitation	$\delta_L \times \lambda_L = \ell_P^2$	Qualitative mechanism
10	$\Lambda = 4 \ln 2 (1 - \alpha \ln 2) / (c \tau_L)^2$	1.10×10^{-52}	Dictionary calibration
11	$ \dot{\alpha}/\alpha \sim 10^{-18} \text{ yr}^{-1}$	—	Independent prediction
12	No singularities	$\rho_{\max} = \rho_L$	Axiomatic consequence
13	No UV divergences	Cutoff ℓ_L	Axiomatic consequence
14	Cyclic universe	$\Phi : 0 \rightarrow 1 \rightarrow 0$	Qualitative mechanism
15	Dark energy = pure Lucrons	$\rho_\Lambda \propto (1 - \Phi)$	Qualitative mechanism
16	Einstein eq. from Lucron properties	Exact	Consistency derivation
17	Gaussian bump IS particle	4 properties	Postulate + identity
18	Lucron unobservable	Fundamental	Axiomatic consequence
19	Sakharov conditions	3 conditions	Qualitative mechanism
20	CP from interaction chirality	Qualitative	Qualitative mechanism

- **Arrow of time:** Emerges naturally from the network conformational entropy gradient.

22.2 What the model does not resolve (Limitations)

- **Specific particle masses:** The values of n are calculated from experimental masses, not predicted from topological first principles.
- **Exact emergence of Lorentz symmetry:** Requires numerical simulation of the discrete graph to prove that the continuum limit recovers the full Poincaré group.
- **Micro-reversibility mechanism:** The exact discrete mathematical rule that cancels diffusive dissipation to yield strict quantum unitarity remains to be formalized.

22.3 Methodological honesty

Following the recommendations of rigorous peer review, we have explicitly classified each result by its epistemic status. We do not claim to have “derived” $\hbar$ or G from nothing; rather, we have constructed a dictionary that maps a discrete, pre-geometric micro-ontology to the continuous macro-world. This transparency allows the community to assess the model’s strengths and limitations honestly.

23 Open Problems

- (1) **Fundamental parameters** w_L, τ_L, ℓ_L . Established as primitive dictionary entries. Their derivation from deeper principles remains open.
- (2) **Specific Lucron counts**. Values of n for each particle must eventually be derived from the topology of the network knots.
- (3) **Exact value of α_0** . Requires numerical simulation of wave scattering in the network.
- (4) **Geometric activation of the Big Bang**. The specific dynamical condition triggering the compaction phase is not yet fully characterized.
- (5) **Quantitative Yang–Mills correspondence**. Requires numerical simulation of the discrete graph equations.
- (6) **Knot classification**. The exact mathematical knot–mass relation requires advanced topological tools.
- (7) **Lorentz emergence**. Proving that the statistical continuum limit of the discrete causal delays exactly recovers Lorentz invariance.
- (8) **Unitarity proof**. Formalizing the discrete micro-reversibility rule that guarantees probability conservation in the emergent Schrödinger dynamics.

24 Future Work

24.1 Numerical simulations

- Simulate the Lucron network on a lattice to verify the emergence of macroscopic constants and Lorentz invariance.
- Simulate wave scattering on the discrete network to determine α_0 from first principles.
- Simulate black hole formation and evaporation to verify the emission-absorption equilibrium and the topological untieing mechanism dynamically.
- Integrate the coupled (Φ, R) non-linear system to obtain the full cosmological cycle.

24.2 Experimental tests

- Next-generation optical lattice clocks to test $|\dot{\alpha}/\alpha| \sim 10^{-18}$ per year.
- Gravitational wave observations to test black hole restitution dynamics.
- Cosmological surveys to test the specific dark energy evolution predicted by $\rho_\Lambda \propto (1 - \Phi)$.
- Search for primordial black holes with $M < 3 \times 10^{22}$ kg (the model predicts they should not exist).

25 Conclusions

We have presented the Lucron Model, a discrete pre-geometric framework and dictionary that:

- Maps three fundamental interactional parameters (w_L, τ_L, ℓ_L) to macroscopic observables $(\hbar, G, \Lambda)$.
- Shows ℓ_P identified with the Lucron interaction range (algebraic identity).
- Explores the Schrödinger equation as discrete diffusion via Wick rotation (qualitative mechanism).
- Models gravity as emergent network deformation, yielding $\delta \times \lambda = \ell_P^2$ (algebraic identity).
- Shows that the elementary gravitational deformation unit is a single Lucron, and that the graviton emerges as a collective excitation of the network.
- Recovers the Bekenstein–Hawking entropy and Hawking temperature via horizon counting (consistency derivations).
- Predicts a strict minimum black-hole mass $M_{\min} \approx 3 \times 10^{22}$ kg (independent prediction).
- Establishes the geometric contraction $\mu^2 + \nu^2 = 1$ (algebraic identity).
- Proposes topological classifications for the Standard Model and CP violation from fundamental interaction chirality (qualitative mechanisms).
- Develops the dynamics of Φ coupled to Friedmann equations, yielding a bounded cosmological drift of α (independent prediction).
- Presents a network thermodynamics with an arrow of time and a cyclic entropy reset that preserves underlying unitarity.
- Explicitly addresses the ontological tensions of Lorentz emergence, information conservation, and quantum unitarity.

We regard the Lucron Model not as a final Theory of Everything, but as a structured, falsifiable research programme. Its ultimate value will be judged by its two independent predictions and by future numerical simulations of the discrete network.

Declarations

Data Availability

Data sharing is not applicable to this article as no new experimental datasets were generated or analyzed during the current study. All numerical data used for verification (e.g., particle masses, standard physical constants) are derived from publicly available standard references, specifically the Particle Data Group (PDG) Review of Particle Physics [9].

Competing Interests

The author declares no competing financial or non-financial interests, nor any personal or professional affiliations that could be perceived to impact the reporting of the research outcomes presented in this work.

Use of Large Language Models (LLMs)

In accordance with standard authorship policies, the author discloses that Large Language Models (LLMs) were utilized during the preparation of this manuscript strictly for structural formatting, linguistic refinement, translation, and literature organization. The LLMs did not generate the core scientific hypotheses, mathematical derivations, or physical conclusions. The sole author takes full accountability for the scientific content, the accuracy of the mathematical proofs, and the final interpretations of the results.

Authorship

The sole author (G.A.C.R.) conceived the theoretical framework, performed all mathematical derivations, conducted the numerical verifications, and wrote the main manuscript text.

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A Appendix A: Detailed Derivations

A.1 Dictionary entry: $\hbar = 2\pi w_L c^2 \tau_L$

The Lucron has interaction weight w_L and causal delay τ_L . The action scale of one causal transition is:

$$S_L = w_L c^2 \tau_L \tag{36}$$

The quantum of action is defined as 2π times the Lucron action scale:

$$\hbar = 2\pi S_L = 2\pi w_L c^2 \tau_L \tag{37}$$

Epistemic status: Dictionary calibration.

A.2 Dictionary entry: $G = V_L c / (2\pi w_L \tau_L \ell_L)$

From the macroscopic Einstein field equation:

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \quad (38)$$

In the Lucron framework:

$$G_{\mu\nu} = \frac{4V_L}{c^3 w_L \tau_L \ell_L} T_{\mu\nu} \quad (39)$$

Equating the coefficients:

$$\frac{8\pi G}{c^4} = \frac{4V_L}{c^3 w_L \tau_L \ell_L} \implies G = \frac{V_L c}{2\pi w_L \tau_L \ell_L} \quad (40)$$

Epistemic status: Dictionary calibration.

A.3 Identity: $\ell_P = \ell_L$

$$\ell_P^2 = \frac{\hbar G}{c^3} = \frac{(2\pi w_L c^2 \tau_L) \left(\frac{V_L c}{2\pi w_L \tau_L \ell_L} \right)}{c^3} = \frac{V_L}{\ell_L} = \frac{\ell_L^3}{\ell_L} = \ell_L^2 \quad (41)$$

Therefore $\ell_P = \ell_L$. **Epistemic status:** Algebraic identity.

A.4 Consistency: $S_{BH} = k_B A / (4\ell_P^2)$

The event horizon has area A . Each Lucron on the horizon has emergent area $A_L = 4\ln(2)\ell_L^2$ and carries entropy $S_L = \ln 2$. Number of Lucrons on the horizon:

$$N_A = \frac{A}{A_L} = \frac{A}{4\ln(2)\ell_L^2} \quad (42)$$

Total entropy:

$$S_{BH} = N_A \times k_B S_L = \frac{A}{4\ln(2)\ell_L^2} \times k_B \ln 2 = \frac{k_B A}{4\ell_L^2} = \frac{k_B A}{4\ell_P^2} \quad (43)$$

Epistemic status: Consistency derivation.

A.5 Consistency: $T_H = c^5 \tau_L / (4G n k_B)$

The Hawking temperature is:

$$T_H = \frac{\hbar c^3}{8\pi G M k_B} \quad (44)$$

Substituting $\hbar = 2\pi w_L c^2 \tau_L$ and $M = n w_L$:

$$T_H = \frac{2\pi w_L c^2 \tau_L \cdot c^3}{8\pi G n w_L k_B} = \frac{c^5 \tau_L}{4G n k_B} \quad (45)$$

A.6 Independent Prediction: $M_{\min}$

The density of a Schwarzschild black hole is:

$$\rho_{BH} = \frac{M}{\frac{4}{3}\pi r_s^3} = \frac{3c^6}{32\pi G^3 M^2} \quad (46)$$

Setting $\rho_{BH} = \rho_L = w_L/V_L$:

$$M_{\min} = \sqrt{\frac{3c^6}{32\pi G^3 \rho_L}} \quad (47)$$

B Appendix B: Numerical Calculations

B.1 Verification of $\hbar$

$$\begin{aligned} \hbar &= 2\pi w_L c^2 \tau_L \\ &= 2\pi \times 3.54 \times 10^{-70} \times 9 \times 10^{16} \times 5.28 \times 10^{17} \\ &= 1.058 \times 10^{-34} \text{ J} \cdot \text{s} \end{aligned} \quad (48)$$

Experimental: $1.055 \times 10^{-34} \text{ J} \cdot \text{s}$. Error: 0.3%.

B.2 Verification of G

$$\begin{aligned} G &= \frac{V_L c}{2\pi w_L \tau_L \ell_L} \\ &= \frac{(1.616 \times 10^{-35})^3 \times 3 \times 10^8}{2\pi \times 3.54 \times 10^{-70} \times 5.28 \times 10^{17} \times 1.616 \times 10^{-35}} \\ &= 6.67 \times 10^{-11} \text{ m}^3 \text{kg}^{-1} \text{s}^{-2} \end{aligned} \quad (49)$$

Experimental: 6.674×10^{-11} . Error: 0.06%.

B.3 Verification of S_{BH} for a solar-mass black hole

Schwarzschild radius: $r_s = 2.95 \times 10^3 \text{ m}$. Horizon area: $A = 1.09 \times 10^8 \text{ m}^2$. Number of Lucrons on horizon: $N_A = 1.51 \times 10^{77}$. Entropy:

$$S_{BH} = N_A k_B \ln 2 = 1.44 \times 10^{54} \text{ J/K} \quad (50)$$

Standard Bekenstein–Hawking yields the exact same value. Error: 0%.

B.4 Verification of T_H for a solar-mass black hole

$$\begin{aligned} T_H &= \frac{c^5 \tau_L}{4G n k_B} \\ &= \frac{(3 \times 10^8)^5 \times 5.28 \times 10^{17}}{4 \times 6.674 \times 10^{-11} \times 5.62 \times 10^{99} \times 1.38 \times 10^{-23}} \\ &= 6.2 \times 10^{-8} \text{ K} \end{aligned} \quad (51)$$

Standard: $6.17 \times 10^{-8} \text{ K}$. Error: 0.5%.

B.5 Verification of $M_{\min}$

$$\begin{aligned} M_{\min} &= \sqrt{\frac{3c^6}{32\pi G^3 \rho_L}} \\ &= \sqrt{\frac{2.19 \times 10^{51}}{2.51 \times 10^6}} \\ &= 2.95 \times 10^{22} \text{ kg} \end{aligned} \tag{52}$$